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Loomis,
Hiram B.
1890
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A STUDY OF THE EFFECTS
OF
CHANGES OF TEMPERATURE
ON
PERMANENT MAGNETISM.

A Thesis presented for the
degree of Doctor of Philosophy
in the
Johns Hopkins University.

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1890.

By
Hiram B. Loomis.

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The following paper is an account of some experiments which were undertaken to determine more accurately, if possible, the kind of change that takes place in magnets which have been brought to the "permanent state" and are subjected to changes in temperature.

A short account will first be given of the work that has been done on this subject, with particular reference to such parts of it as concern magnets in the "permanent state".

II.

HISTORY.

A. INVESTIGATIONS ON THE CHANGE IN MAGNETIC MOMENT DUE TO CHANGE IN TEMPERATURE.-

Kupffer (I) found that if a permanent magnet was heated above the temperature at which it was magnetized, its magnetic moment decreased; that, on cooling the moment increased, but not enough to make up for the first loss, and that this happened for the first three or four times the magnet was heated.

Note (I) Kastner's archiv. 6 p. 185.
Wied. Elec.III.p.753

He made his experiments by putting the magnet under investigation in a water bath, near which a magnetic needle was suspended by a silk fibre. The time of 300 swings of this needle was determined, when the water in the bath was at the temperature of the room, at 100 C, again at the temperature of the room, etc..

(I)

Lamont found that if a magnet was alternately heated and cooled for fifteen or sixteen times between two given limits of temperature it reached a permanent state, in which it had a definite magnetic moment corresponding to a given temperature, to which it always returned when brought to that temperature, provided its temperature has never passed outside the limits referred to above. The magnetic moments were smaller, the higher the temperature.

(2)

Riess and Moser experimented on the change in moment by swinging magnets at different temperatures and determining the time of vibration. For needles 34 Paris lines in length they found that the following formula held

$$I' = I \left[1-0.000324 \ (t'-t) \ d\right]$$

Note (1) Pogg Ann. 82 p.440.
(2) Pogg Ann. 17 p.430

Where I and I' are the intensities of magnetization at the temperature t and t', on the Reaumur Scale, respectively and d is the diameter of the magnet. For needles 2 in. long the numerical factor in their formula becomes 0.000432, showing that the proportional change in intensity of magnetization is greater in the shorter magnets. Their limits of temperature were 0° and 80° on the Reaumur Scale. By swinging their needles at different temperatures within these limits, they found that the change in moment was proportional to the difference in temperature; that is the factor (t' - t) enters in the formula in the way given above. To determine the factor d, rods of the same length, but of different diameters were employed. For example, they give the following for magnets 34 Paris lines long.

Diameter in Paris lines	Temperatures	Numerical factor in formula
0.93	(5° + 74° - 72° R	0.0003202
	(8° + 68° - 58° R	0.0003158
1.16	0° + 74° - 70° R	0.000324
0.67	Difference of 59° R	0.0003286

From these results the factor 0.000324 in their formula is ob-

tained.

Professor G. Wiedemann (1) has made some careful investigations on the effects the temper and the original intensity of magnetization of the bar have on these phenomena. He used bars 22 cm. long, and 1.35 cm. in diameter, which before being magnetized were placed alternately in melting snow and boiling water fifteen times, in order to bring the steel itself as far as possible to a state in which it would undergo no structural change from a change in temperature. These bars were then magnetized in a coil at a temperature of 0°, care being taken to prevent jarring, and were placed in a box of sheet copper, before the needle of a galvanometer, the deflection of which was observed by a telescope. The temperatures 0° and 100° were obtained by means of melting snow and boiling water. The table on page 33 gives the results found in this way. M_0 is the intensity of magnetization before it has suffered any change in temperature. M_{100} is the intensity when first heated to 100°; $\underline{M'_0}$ is the same after being cooled to 0°. N_0 and N_{100} are the intensities of magnetization at the temperatures indicated by the subscrips after the magnet has been heated and cooled fifteen times.

Note (1) Pogg Ann. 122 p.355 also 100 p.235 and 103 p.563

With respect to magnets that have reached the permanent state, a study of the table shows: in the case of hard steel the change of moment is nearly proportional to the moment at 0°, while for tempered or soft steel the ratio of change to moment at 0° is greater the greater the moment. In the curves on page 38, n's are plotted as abscissae and $\frac{n_1 - n}{n}$ as ordinates.

With reference to the theory of these changes, Professor Wiedemann says: "Besides the permanent effect due to alteration in temperature, there is a temporary change. Each heating diminishes the permanent moment of the molecules. Moreover, for the time, it loosens the particles of the body, and lessens the strain in which they have been placed by the action of external forces, therefore, they return a little towards their first position of equilibrium, in which they were held by the forces acting between them, before the external forces came into play. Heating thus diminishes the magnetization temporarily, but on cooling, the molecules return to their former position, and the lost magnetization is regained."

(1)
Barus and Strouhall carefully distinguished the me-

Note. (1) Bull U.S.Geol. Sur. No.14 p.151.

chanical effect of heating from the purely magnetic effect. They found that temperature 20 or 30° above that of the water in which a glass hard steel rod was dipped during tempering, produced quite perceptible annealing effects. This change in the hardness of the steel would naturally affect the magnetization. According to their experiments, if a glass hard rod is thoroughly annealed by being kept at temperature t' for a day or two, and then magnetized to saturation at the ordinary temperature t, the loss in specific magnetism on heating to t' is relatively small, and is nearly independent of the time t' acts; nearly the whole change takes place during the first ten minutes. On the other hand, if the bar is not first annealed, the change is not complete after twenty-two hours of heating.

B. INVESTIGATIONS ON THE EFFECT OF CHANGE OF TEMPERATURE ON THE DISTRIBUTION OF MAGNETISM.

This part of the subject has not been so extensively worked out, the investigations of Kupffer and Poloni being all that could be found.

Kupffer (1) determined at two different temperatures the

Note (1) Pogg. Ann. X11. p 135.

period of vibration of a short needle placed opposite different parts of a long magnet, and found the proportional change in distribution greater at the ends than in the middle of the bar. All his measurements were made before the bar had reached the permanent state.

Poloni[(1)] measured the distribution at various temperatures by slipping a coil from different parts of the magnet to such a distance that the magnet exerted practically no effect, and measuring the current thus induced. He worked between temperatures 0° and 200 C using an oil bath to obtain his higher temperatures. The changes were quite regular between 0° and 180° C, but very great near 190°. Between 0° and 180° he found that the following formula held

$$M - A \left[1 + k^{-l} - k^{-x} - k^{-(l-x)}\right]$$

where M is the induction in the magnet at a distance X from one of the ends, l is the length of the magnet; A a quantity depending only on the temperature, while k is sensibly constant for a given magnet.

111. EXPERIMENTS.

The existence of a permanent state in which the moment of the magnet increases or diminishes as the temper-

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Note (1) Beibl V. p. 802

ature falls or rises, being now well established, it becomes a question of great interest as to how this change is brought about. It was thought that the explanation might be found in a change in the distribution of magnetism, the magnetism being less concentrated at the ends of the magnet at the higher temperature; or that the magnetism might be a function of the temperatures. In order to obtain some clue, if possible, to the real nature of the change in the magnetic moment, the following investigation was undertaken. The experiments were planned to determine:

FIRST, the change in moment due to change in temperature in bars of the same cross-section, but of different lengths;
SECOND, the change in distribution caused by change in temperature.

The experiments will be considered in the above order.

A. EXPERIMENTS ON THE CHANGE OF MOMENT OF MAGNETS OF DIFFERENT LENGTHS, BUT HAVING THE SAME CROSS-SECTION.

Stubb's steel wire of square cross-section, 0 . 159 cm square was cut into lengths of approximately 5.5 cm 8. 3 cm and 22.cm. The steel was soft, and was used of the

same temper as purchased. The bars were annealed in boiling water, magnetized to saturation in a coil, and were in the permanent state when used.

The time of vibration in the earth's field was determined at 11° and 99° C. A double box of thin sheet zinc was used to keep the magnets at the required temperature. In the top of the box was a round opening into the interior, in which a cork holding a thermometer and a glass tube, was inserted. Through this tube passed a short wire, which supported the magnet, and was suspended from the ceiling by cocoon silk. The suspension was thus quite long, and was but little exposed to the action of the heat. The bulb of the thermometer was close to the magnet. In the side of the box was another opening covered with glass, through which a mirror, attached to the magnet was observed, and the time of vibration thus determined. The temperature of the space in which the magnets swung, was kept quite constant at 11° C. or 99° C, by passing a current of cold water or steam through the space between the two parts of the double box. For the lower temperature city water was used direct from the faucet. The magnets and the mirror used in observing their vibrations were

weighed.

CALCULATION OF RESULTS.

The lengths of the magnets were measured at the ordinary temperature of the room 18 C. The corrected lengths for 11° and 99° were obtained by the following formulae-

$$L_{11} = L\,(1 - 7 \times 0.000011)$$

$$L_{99} = L\,(1 - 81 \times 0.000011)$$

where L_{11} and L_{99} are the lengths at the temperature indicated by the subscripts, L is the observed length, and 0.000011 is the coefficient of linear expansion of untempered steel. The moments of inertia for the magnets at each temperature were calculated as follows:

$$I_{11} = m\,\frac{L_{11}^2 + b^2}{12}$$

$$I_{99} = I_{11}\,\frac{L_{99}^2}{L_{11}^2}$$

where m is the weight of the magnet, and b is its thickness. The weight of the mirror and the appliances by which it was fastened to the magnet, was 0.4245 grms - and calling its radius of gyration 0.2 cm, the moment of inertia due to it was 0.0170, which was added to that of the magnets. No correction

was made for the rest of the suspending apparatus, its weight was always less than 0.10 grms, and consisted principally of a piece of fine wire about 25 cm long, by which the magnet was suspended from the end of the silk suspension, and its radius of gyration was therefore exceedingly small, being a fraction of the diameter of the wire. The silk suspension was about 3.5 metres long, and no allowance was made for the effect of tortion. The magnet could be turned enough, 360° and no difference in its azimuth could be detected by a telescope and scale at a distance of 3 m. The formulae for the magnetic maments are

$$M_{11} = \frac{4I'_{11}\,\pi^2}{T^2\,H}$$

$$M_{99} = \frac{4\,I'_{99}\,\pi^2}{T^2\,H}$$

where I' denotes the total moment of inertia of the system at the temperature indicated; T is the period of a complete vibration, and H is the horizontal intensity of the earth's magnetic force. H was taken as equal to 0, 2. It has been determined by several previous observers in various parts of the room in which the work was done, and as there w~~as~~re no local disturbing iron masses, that part of the building being kept

free from iron, it may be taken as within one-half of one per cent of correct.

SPECIMEN CALCULATION.

Magnet No.9.

Length at 18° C = 16.40 cm.

Weight = 3.609 grms.

Period of vibration at 11° C = 10.435 sec.

" " " " 99° C = 10.812 "

$L_{11} = 16.40\ (1 - 7 \times 0.000011) = 16.399$ cm

$L_{99} = 16.40\ (1 + 81 \times 0.000011) = 16.414$ cm

$$I_{11} = m\,\frac{L_{11}^2 + b^2}{12} = \frac{3.609\,(268.92 + 0.02)}{12} = 80.883$$

$$I_{99} = I_{11}\,\frac{L_{99}^2}{L_{11}^2} = 80.883\,\frac{269.43}{268.91} = 81.034$$

$I'_{11} = 30.883 + 0.017 = 80.900$

$I'_{99} = 81.034 + 0.017 = 81.051$

$$M_{11} = \frac{4\ I'_{11}\ \pi^2}{T_{11}^2\ H} = 146.64$$

$$M_{99} = \frac{4I'_{99}\ \pi^2}{T_{99}\ H} = 136.80$$

The intensity of magnetization was obtained by dividing the magnetic moment of each magnet by its volume.

B. EXPERIMENTS ON THE CHANGE IN MAGNETIC DISTRIBUTION.

The apparatus employed was devised by Professor Rowland, under whose direction the whole investigation was conducted, and will be best understood from the diagram.

A and B are two cylindrical soft steel magnets, 30.1 cm long and 0.55 cm in diameter. They were magnetized to saturation in a coil, and then brought to the permanent state by alternate heatings and coolings. These magnets were placed perpendicular to the magnetic meridian. In both ends of each, holes were bored and threads cut. The depth of these holes in magnet A was 8 m.m. for each end. In magnet B the hole at the S end, was 11 m.m. deep, that at the N. end 7 m.m. Pieces of brass rod, H H H H, of the same diameter as the magnets were screwed into the ends, and acted as guides for the two coils, to be described presently, so that after they had been slipped off the magnets they could be slipped back again without any trouble. D D is a brass rod about

1 1/2 metres long, holding the two magnets together in the position shown in the figure. C C are pieces of non-conducting material to keep the magnets from changing temperature by conduction along the rod joining them. E and F are two coils of very fine wire wound on paper tubes which just fit the magnets. They consisted of 150 turns (5 layers of 30 turns each) and were about 7 m.m. wide. Their frames were joined together by a brass rod, P P, of such length that when the coil E was at the centre of the magnet A, the coil F was also at the center of the magnet B. By means of this rod they could be moved simultaneously over corresponding portions of the two magnets. At G, is a gauge which regulates the distance through which the coils are moved at one time, so that as the coils are moved, step by step, from one end of the bar to the other, the steps will be of equal length. By loosening a screw the coils may be moved from the middle of the magnets to either end at one step.

The cross-sections of the two cylindrical double boxes, made out of sheet zinc, are indicated at S T. At K K are openings in which corks, holding thermometers were inserted. At L L L L ~~are~~ are openings into the space between

the two parts of the double box. Through these a current of steam or cold water was passed to keep the space containing the magnets at the requisite temperature. The temperatures employed were 14° C and 99°5 C. M N, M N, are other openings by which the magnets were introduced, and through which the bars D D and P P passed. They were about 2.5 cm in diameter, and about 20 cm in length, and were stuffed with cotton, the better to maintain the temperature of the interior.

The exploring coils were connected up with an ordinary astatic galvanometer of rather low resistence coils in such a way that the currents induced by moving them along the magnets opposed each other. An earth inductor and a resistance box were included in the circuit, and in each experiment the galvanometer readings were standardized by the earth inductor. Beginning at the middle of the magnets, the coils were moved step by step to one end, the throw of the needle being observed at each step. The coils were moved so far in the last measurement that practically no lines of induction passed through them, as was determined by experiment. Similar observations were then made over the other half of the magnets.

In this way was measured the excess of the number of lines of induction passing from one magnet into the medium in the distance the coils move, over that passing out from the corresponding portion of the other magnet, thus giving the difference of distribution in the two magnets. These measurements are taken first (say) when A and B are both at 14° C, and again when A is at 14° C, but B at 99°.5 C. The difference between the two after they have been reduced to the same scale by the earth inductor readings, is evidently the change in distribution in B, due to the change in the temperature. By this method the quantity observed is of about the same magnitude as the quantity we desire to obtain. In these experiments the greatest throw of the needle was but little over twice the largest difference obtained on subtracting the two sets of observations.

To get the distribution in the bars, the difference of distribution was first measured as above, at the lower temperature; then the connections were changed, so that the currents induced in the two coils were in the same directions, and the sum of the distributions was obtained in the same way. In this case, extra resistance had to be put in from the resistance box to keep the readings on the scale.

CALCULATION OF RESULTS.

The formula for the ballistic galvanometer is -

$$Q = k \sin \frac{\vartheta}{2}$$

where Q is the quantity of electricity; k a constant factor; and ϑ the angular throw of the needle. The observations were made with telescope and scale. Calling d the observed throw, and r the distance of the mirror from the scale,

$$\tan 2\vartheta = \frac{d}{r}$$

expanding the sin $\frac{\vartheta}{2}$ we have -

$$\sin \frac{\vartheta}{2} = \frac{d}{2\,r} \left[1 - 0.344 \left(\frac{d}{r} \right)^2 + \right.$$

This formula was used in reducing the larger readings.

Corresponding throws of the needle were averaged up just as they were taken. The throw of the earth inductor, when both magnets were at 14°, was 39.5 scale divisions, it was takenfrequently, and varied but very little. When one magnet was at 99°.5 and the other at 14° it was 37.8. The average throw taken when one magnet was hot and the other cold, was then multiplied by $\frac{39.5}{37.8} = 1.045$, to reduce to the same

scale as the readings taken when both magnets were at 14°. Corresponding readings were then subtracted to get the difference in distribution caused by change of temperature in terms of the scale divisions. The reduction to absolute measure was as follows:

The effective area of the earth inductor, as determined by previous observers is 20716 sq. cm. The total number of lines of lines of induction cut was therefore
$2HA = 8286.4$; the throw was 39.5 scale divisions, therefore each scale division corresponded to
$8286.4 \div (39.5 \times 150) = 1.398$ C G.S. lines of induction where the factor 150 is due to the 150 turns in each of the coils. The change in distribution as given in scale divisions, was then multiplied by 1.398, giving the change in linear distribution in C.G.S. lines of induction per 2.17 cm, that being the distance the coils were moved at each step. In determining the difference of distribution, the angles observed were quite small, the largest being less than 2° making the angular throw of the needle less than 1°. The quantities measured by the galvanometer were therefore taken as simply proportional to Q in the formula, the error in case of the largest readings not amount-

ing to more than one part in 3500, and as the results are obtained by subtracting two throws, the error in the result is still less, being the difference of the errors in the two.

SPECIMEN CALCULATION.

Magnet A.

Middle to N.End.

	Average throw 14	Average throw 99.5	Corrected throw 99.5	Diff. in distribution in scale divisions.	Diff. in Distribution Number of lines of induction per 2.17 cm length.
1.	18.0	17.5	18.3	0.3	0.4
11.	18.4	18.1	18.9	0.5	0.7
111.	11.8	12.6	13.2	1.4	2.0
1V.	07.2	04.2	04.4	2.8	3.9
V.	34.3	27.2	28.4	59	8.3
V1.	42.0	27.7	28.9	13.1	18.3
V11.	49.0	19.4	20.3	28.7	40.2
End.	05.4	02.2	02.3	03.1	4.3

In getting the sum of the distributions, it was found necessary to make use of the formula given on p. 18 because the angles were too large to take $\sin \frac{\vartheta}{2}$ proportional to $\tan 2\vartheta$. The corrected readings were reduced to absolute measure in the way already described. Thus we have the sum and difference of the linear distributions of the two magnets in absolute measure. The distribution in one magnet is equal to one half the sum plus one-half the difference of the distributions, that in the other, is one-half the sum minus one-half the difference. The distributions at the higher temperature were obtained by subtracting the change in distribution due to heating from the distribution at the lower temperature. The induction at each point of the magnet was obtained by adding up the number of lines of induction passing out of that portion of the magnet which was beyond the point in question. Tables of the results for the magnets A and B are given on pages 35 & 36. The first column gives the distance of the exploring coils from the centres of the magnets at the end of each step. The second and fourth columns give the number of C.G.S. lines of induction passing out from the

magnet at 14° and $99^{\circ}.5$ in the step of the coil shown in the first column. The third column gives the change in distribution. The fifth and sixth columns give the magnetization at the two temperatures, i.e., the number of C.G.S. lines of induction per sq.cm. of cross-section passing through the magnet at the point indicated. In these columns two values are given for the middle point of the magnet, calculated from the two ends, and serve to indicate the degree of accuracy attained.

The second and third columns from which all the others are calculated, are the mean of at least five or six separate determinations, which agreed well among themselves. The result was further checked by slipping the coils from the middle of the magnets off each end at both temperatures. The variation between this measurement and the other, was always less than 1/2 of one per cent, which was considered quite good, as it is impossible to slip the coils over this whole distance at the same rate at which they were slipped over the small divisions.

On pages 40 and 41. curves for the magnets A and B respectively, are given. The curves are:

A A	The distribution curve at 14° C
B.B.	The distribution curve at 99°.5 C
C C	Curve giving the change in distribution due to the change in temperature (14° - 99°.5). The scale of ordinates is ten times that in curves A A and B B
E E	Curve giving the induction in the magnet at 14° C
F F	Induction at 99°.5 C

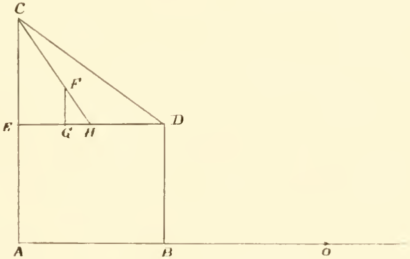
On page Fig.3 gives curves for magnet A, in which $\frac{I_{14} - I_{99.5}}{I_{14}}$ are ordinates, and I_{14} abscissae. N is the curve from the north half, and S for the south half of the magnet. Fig. 4 gives the same curves for magnet B. The point ⊙ gives the value for the S end of this magnet. The hole in this end of the magnet is 11 m.m. deep, while that in the other end is 7 m. m. deep. I am inclined to think that this causes its deviation from the other curve. In fact these holes in the ends of the magnets must have affected the distribution there.

The tables on pages 35 and 36 together with the curves for distribution, give us sufficient data to calculate the magnetic moments of the magnets A and B

at both temperatures. In the table we are given (n) the number of lines of induction, issuing from little divisions of the bar throughout its length, as well as the distances (d) of the centre of these divisions from the centre of the magnet. A first approximation to the moment is given by the formula

$$M = \frac{1}{4\pi} \sum nd.$$

To this value, the following correction was added -



If A B is the length of one of the divisions of the magnet, and C D, a part of the distribution curve supposed to be straight, then the area A B D C, represents the number of lines of induction issuing from the magnet in the length A B. Let F be the centre of gravity of the trian-

gle C E D. It is evident that that portion of the distribution represented by the triangle C E D should be multiplied by the abscissa of F not by the abscissa of H, therefore a correction area of C E D x G H was added.

$$G\ H = 1/6\ A\ B, \text{ and area of } C\ E\ D, = \frac{c\ e}{2.c\ A} \times$$

area A B D C.

From this calculation, the following results were obtained:

	Magnets	A	B
M_{14}	Moment at 14°	2298.	2060
$M_{99°}$	" at 99°	2140.	2018
	Difference	158.	142
	$\frac{M_{14} - M_{99}}{M_{14}}$	0.0687	0.0689
	Intensity at 14°	322.	289.
	" at 99°	300.	283

The magnetic moments were also determined by the method used in the first part of this investigation, with the following results:

Magnets		A	B
M_{14}	Moment at 14	2359.	2091.
M_{99}	" at 99	2197.	1947.
	Difference	166.	145.
	$\frac{M_{14} - M_{99}}{M_{14}}$	0.0686	0.0687
	Intensity at 14	330. ~~339.~~	293.
	" " 99	308. ~~315.~~	272.

The difference between these two sets of values for the magnetic moments is considerable, in the case of magnet A amounting to 2 %. This is probably due to the fact that only an approximation could be made to the moments of inertia of the magnets, because of the holes in the ends, where a slight error would affect the result materially, the distance from the centre being 15 cm.

The moments of inertia were calculated by dividing the magnets into two parts, an inner core and an out~~side~~er shell which extended beyond the core at both ends. On the other hand, it is to be noticed that the ratios $\frac{M_{14} - M_{99}}{M_{14}}$ differ by less than one part in 300.

In his paper on Magnetic Distribution,[1] Professor Rowland gives the following formula for the linear distribution in a magnet

$$\lambda = \frac{\mathfrak{S} \, (\varepsilon^{rx} - \varepsilon^{-rx})}{4\pi\sqrt{RR'}\,(\varepsilon^{rb} + \varepsilon^{-rb})}$$

where

R is the resistance of unit of length of the rod

R' is the resistence of medium along unit of length of the rod.

2 b is the length of the magnet

x is the distance from the center of the magnet

and $r = \sqrt{\frac{R}{R'}}$

At 14 C the formula for Magnet A, may be written

$$4\pi\lambda = 167. \frac{\varepsilon^{.125x} - \varepsilon^{.125x}}{\varepsilon^{.125b} + \varepsilon^{-.125b}}$$

At 99°.5 C

$$4\pi\lambda = 161 \frac{\varepsilon^{.1242x} - \varepsilon^{.1242x}}{\varepsilon^{.1242b} + \varepsilon^{-.1242b}}$$

Note 1 Phil. Mag Ser IV. Vol. L p 356.

For the higher temperature both the numerical factors ~~would be~~ are a little smaller. Owing to the irregularities in the magnetization of magnet B, no attempt was made to obtain a formula.

IV.

DISCUSSION OF RESULTS.

The curves for the change in distribution on pages 40 & 41 show that there is a loss in magnetism at all points of the magnet, and it is evident that the change in moment is not due, as was thought possible, to a change in distribution, by which the magnetism becomes less concentrated at the ends, but more so in the centre. It is also evident, from these curves, that the proportional change in distribution is greater at the ends than in the centre of the magnet. As a result of this, the proportional change in magnetization is greater at the ends than in the centre, as appears from Fig. I. page 30 These results differ slightly from the formula given by Paloni (see P 8)

$$I = A \left[1 + k^{-\ell} - k^{-x} - k^{-(\ell-x)} \right]$$

in which he found k sensibly constant. for a given magnet, making the proportional change in magnetization the same through-

out the magnet. The method used in the present research admits a much more accurate determination of these small differences, and shows that this is not quite correct.

I am inclined to think that the dimensions of the magnet do not affect the change in magnetic moment due to change in temperature, except as they affect the original intensity of magnetization. Among the magnets, from which the curve on p 39 Fig. 2 was derived, were several pairs of about equal length, but of some what different magnetizations, yet they all give values which lie on a smooth curve. Moreover, the values of $\frac{M_{10} - M_{100}}{M_{10}}$ for the two magnetsA and B, which are altogether different in shape and size, are almost exactly those this curve gives. The curve would then show that within the limits of magnetization used, the proportional change in magnetization is greater the smaller the magnetization, as also appears from the curves on p 39 Figs. 3 and 4, in which the change in magnetization is plotted as a function of the magnetization for different parts of the magnets A and B.

It is to be noticed that the curve on p 39 Fig.2 slopes down, while some curves given from Wiedermann's

observations (p 38) slope up. This may be explained in several ways. In this investigation, magnets of various lengths magnetized to saturation, were employed; he used the same bar at different intensities of magnetization. I am also inclined to think that the magnetizations in my bars were all greater than in his, because even in my shortest magnets, the ratio of length to thickness was almost three times as great as in his bar. Nothing could be found to show in what units his results were expressed, and therefore I can make no positive statement.

In order to find the reason for this difference, it is proposed to continue the investigation by repeating Wiedemann's experiments with bars similar to those I used, and also to repeat the present investigation with bars of such dimensions that the average intensity of magnetization will be less than has been employed so far.

From this may be ascertained:

FIRST, Whether the curve for the proportional change in intensity of magnetization as a function of that intensity

is the same for a single magnet magnetized at different intensities, as for different magnets of the same kind of steel each magnetized to saturation.

SECOND. Whether these curves have the same shape for low as for high intensities of magnetization.

THIRD. Whether the dimensions of the magnet affect the change in moment, except as they affect the original intensity of magnetization.

In order to make the investigation as complete as possible, I intend to find the permeability curves for the steel used at both the temperatures employed in the experiment.

m_0	m_{100}	m'_0	n_0	n_{100}	$\frac{n_0 - n_{100}}{n_0}$
		HARD STEEL.			
71.5	41.5	44.8	37.0	33.2	0.103
134.5	89.2	96.0	85.5	77.5	0.090
195.0	134.3	146.2	133.3	120.0	0.100
		TEMPERED STEEL.			
44.0	27.0	30.0	29.0	27.0	0.0690
148.5	107.2	114.5	110.3	101.0	0.0814
219.5	165.0	179.0	172.0	156.0	0.0930
317.0	239.0	260.7	251.2	226.0	0.1003
		SOFT STEEL BAR No.1.			
85.0	45.0		38.0	33.2	0.126
144.0	73.5		68.5	57.0	0.168
193.0	99.0		101.0	78.5	0.223
209.5	109.5		115.0	88.2	0.233
		SOFT STEEL BAR No.2.			
95.5	49.7	54.2	45.0	39.0	0.133
136.5	73	81.5	69.0	59.0	0.145
174.8	92.5	108.3	93.4	76.0	0.186

MAGNETS OF SQUARE CROSS SECTION.

0.159 cm Square.

Number of Magnet.	Length.	M Moment at 11 C	M Moment at 99 C	M - M --------- M	Intensity of Magnetic action
3.	21.53	232.92	219.88	0.056	427.
5.	22.00	207.08	193.64	0.065	372.
9.	16.40	146.64	136.80	0.067	352.
15.	16.31	139.76	129.28	0.075	338.
4.	11.23	94.76	88.04	0.071	333.
6.	10.80	72.41	65.72	0.092	249.
7.	8.15	43.04	38.48	0.105	208.
8.	8.17	40.48	35.92	0.112	196.
13.	5.49	16.72	14.44	0.141	117.
12.	5.40	12.04	9.84	0.220	38.

MAGNET. A.

Distance from centre of Magnet. N	Distribution at 14 C	Change in Distribution.	Distribution at 99.5 C	I Induction at 14 C	1 Induction at 99.5 C	1 - 1 ------- 1
	70.1	4.3	65.8			
15.20				296.	278.	.060
	428.5	40.2	388.3			
13.03				2106.	1918.	.089
	285.4	18.3	267.1			
10.86				3309.	3044.	.080
	204.9	8.3	196.6			
8.68				4175.	3875.	.071
	146.8	3.9	142.9			
6.51				4795.	4479.	.065
	91.2	2.0	89.2			
4.34				5180.	4856.	.062
	56.6	0.7	55.9			
2.17				5419.	5092.	.060
	18.6	0.4	18.2	(5498.)	(5169.)	
0.				(5453.)	(5126.)	.060
	17.9	0.	17.9			
2.17				5377.	5050.	.060
	55.5	0.4	55.1			
4.34				5143.	4818.	.063
	96.9	2.5	94.4			
6.51				4734.	4420.	.066
	142.1	3.2	138.9			
8.68				4134.	3834.	.072
	199.9	6.2	193.7			
10.86				3289.	3015.	.083
	276.3	14.8	261.5			
13.03				2122.	1910.	.100
	432.6	39.2	393.4			
15.20				294.	247.	.159
	69.7	11.2	58.5			

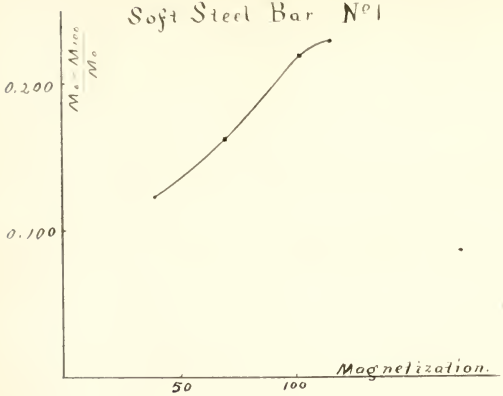
MAGNET B.

Distance from center of magnet	Distribution at 14 C	Change in Distribution.	Distribution at 99.5 C	I Induction at 14 C	I Induction at 99.5 C	$\frac{I - I}{I}$
N				258.	242.	.062
	61.0	3.9	57.1			
15.20				1777.	1594.	.103
	359.5	39.6	319.9			
13.03				2733.	2491.	090
	227.6	15.1	212.5			
10.86				3413.	3141.	079
	159.7	6.0	153.7			
8.68				4002.	3716.	.071
	139.4	3.4	136.0			
6.51				4458.	4163.	.066
	108.1	2.1	106.0			
4.34				4802.	4501.	.062
	81.4	1.5	80.0	(4986.)	(4685.)	
2.17				(4950.)	(4650.)	.060
	43.5	0.1	43.4			
0.				4965.	4668.	.060
	3.6	0.7	4.3			
2.17				4812.	4520.	.060
	36.2	1.1	35.1			
4.34				4475.	4191.	.063
	79.8	2.0	77.8			
6.51				3933.	3659.	.069
	128.3	2.4	125.9			
8.68				3133.	2890.	.078
	188.6	6.6	182.0			
10.86				2011.	1845.	.082
	266.3	19.0	247.3			
13.03				294.	277.	.057
	406.4	35.4	371.0			
15.20						
	69.7	4.1	65.6			

HIRAM B. LOOMIS, the writer of this thesis, was born in Hartford, Conn. June 19th, 1863, and his early education was acquired in the public schools of that city. In 1885 he was graduated at Trinity college (Hartford) with the degree of Bachelor of Arts. During the school year of 1886 - 7, he taught in the Hartford Public High School. Since the Autumn of 1887, he has been engaged in the study of Physics at the Johns Hopkins University, holding a University Scholarship for the year 1888 - 9, and for the past year, a Fellowship.

On Jan. 2nd, 1890 he was married to Miss Carrie E. Kingman of Bridgeport, Conn.

May 30th, 1890.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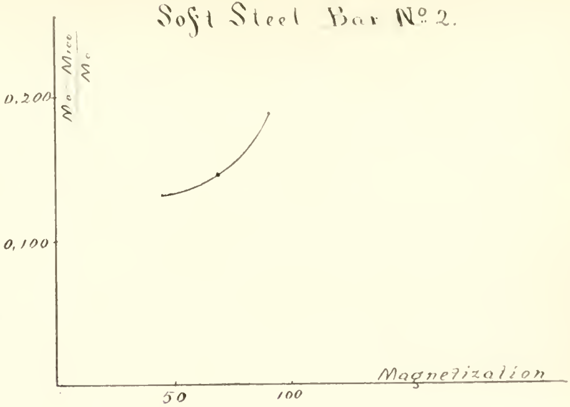
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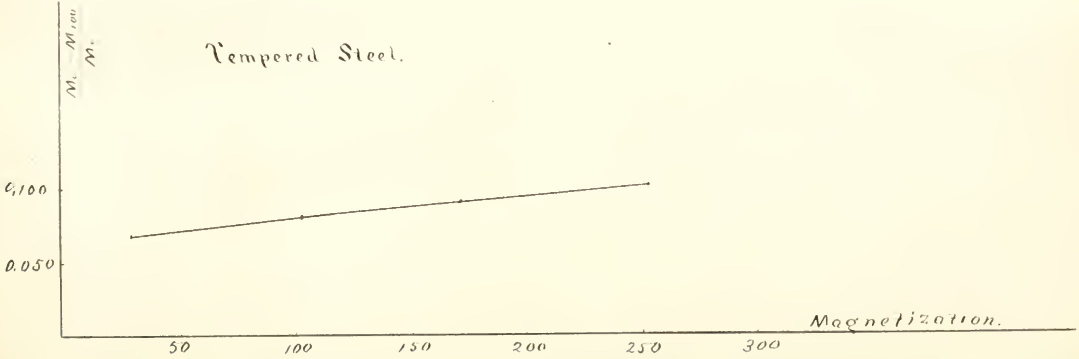
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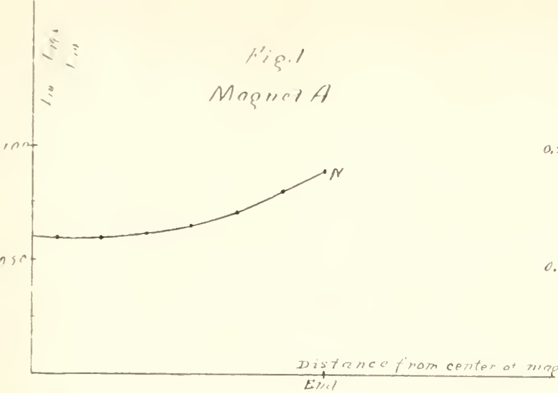


Fig. 1
Magnet A

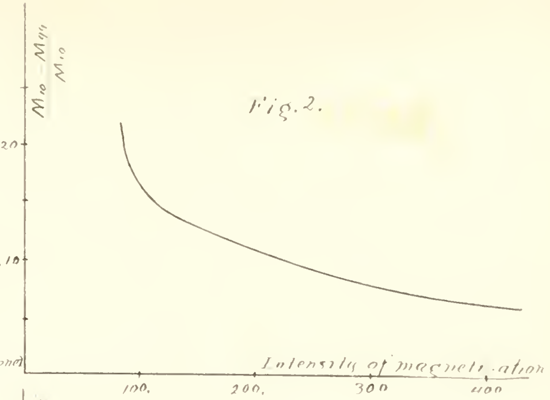


Fig. 2.

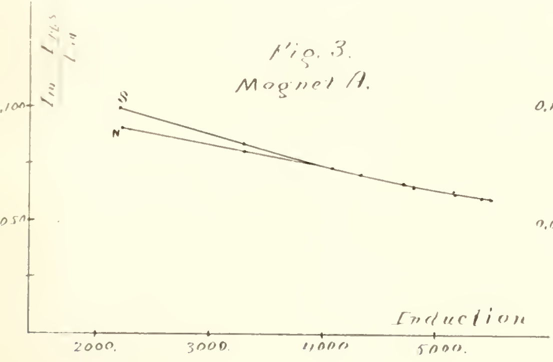


Fig. 3.
Magnet A.

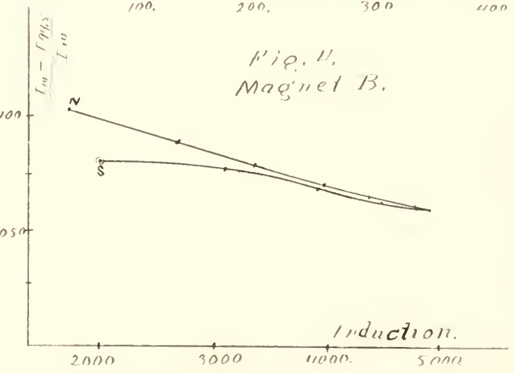
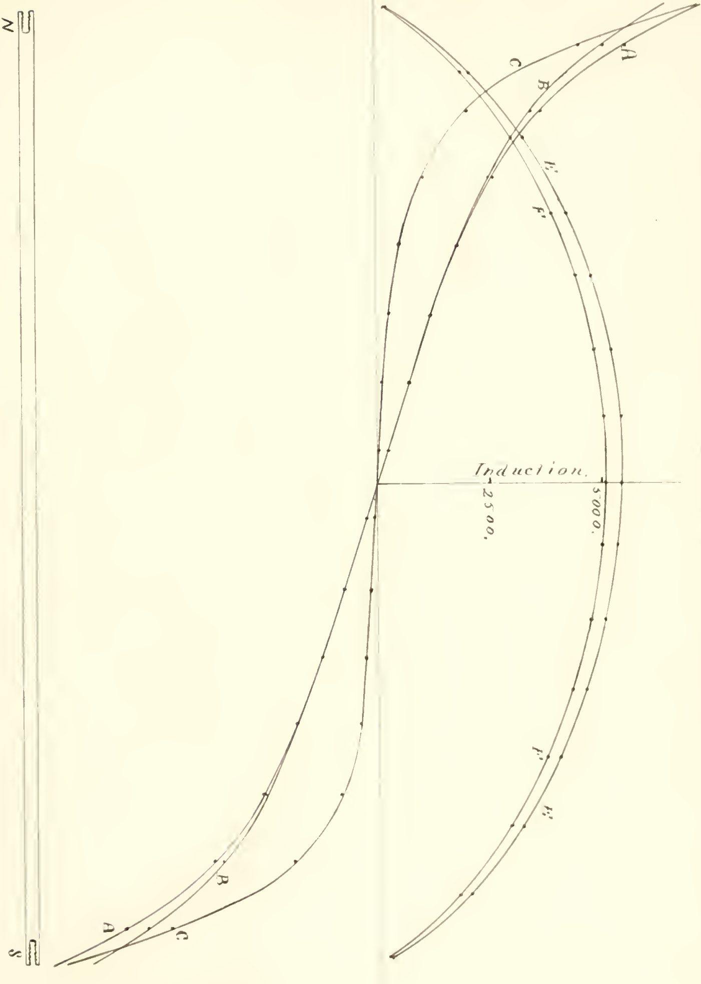
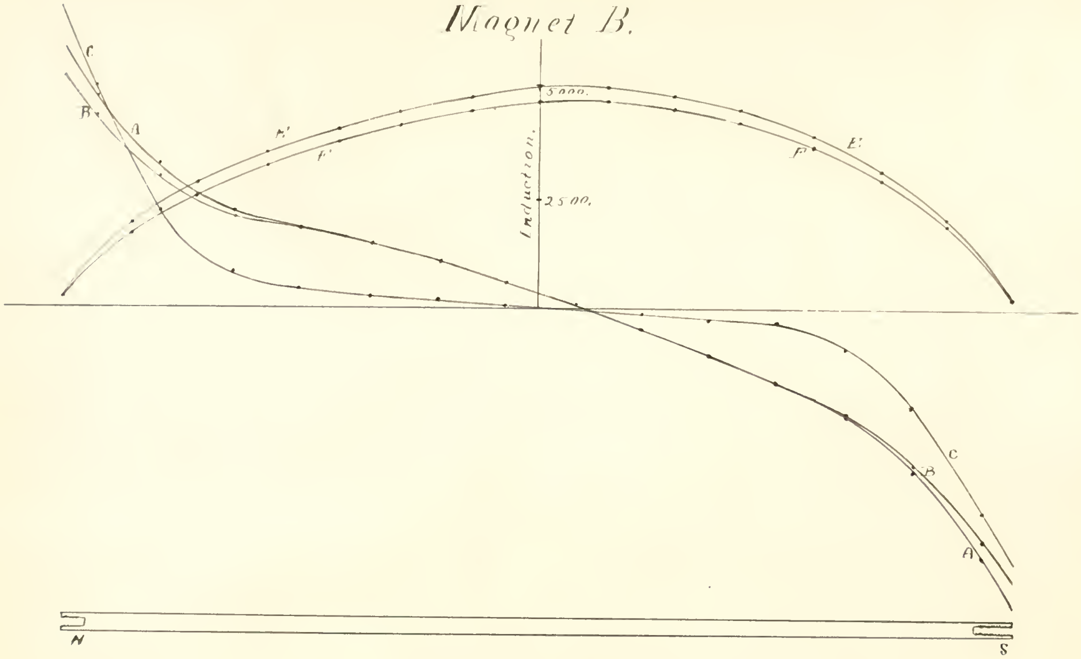


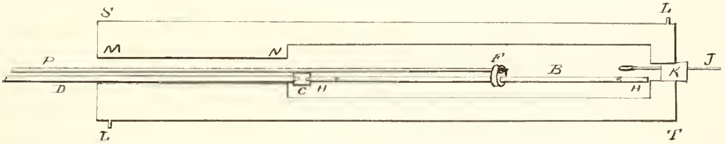
Fig. 4.
Magnet B.

Magnet 1.



Magnet B.

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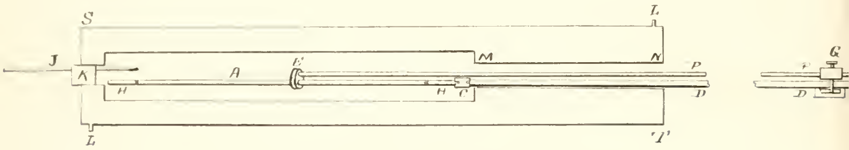
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